A Study on the Operation Strategy for Combined Accident including TLOFW accident

Bo Gyung Kim [a], Ho Joon Yoon [b], Hyun Gook Kang [a*]
[a] *Department of Nuclear and Quantum Engineering, KAIST, 373-1, Guseong-Dong, Yuseong-Gu, Daejeon, South Korea, 305-701*
[b] *Department of Nuclear Engineering, Khalifa University of Science, Technology & Research, Abu Dhabi, UAE*
[*] *Corresponding author: hyungook@kaist.ac.kr*

1. Introduction

It is difficult for operators to recognize the necessity of a feed-and-bleed (F&B) operation when the loss of coolant accident and failure of secondary side occur. An F&B operation directly cools down the reactor coolant system (RCS) using the primary cooling system when residual heat removal by the secondary cooling system is not available. The plant is not always necessary the F&B operation when the secondary side is failed. It is not necessary to initiate an F&B operation in the case of a medium or large break because these cases correspond to low RCS pressure sequences when the secondary side is failed. If the break size is too small to sufficiently decrease the RCS pressure, the F&B operation is necessary. Therefore, in the case of a combined accident including a secondary cooling system failure, the provision of clear information will play a critical role in the operators' decision to initiate an F&B operation [1][2].

This study focuses on the how we establish the operation strategy for combined accident including the failure of secondary side in consideration of plant and operating conditions.

2. Reviews on the operation strategy in emergency operating procedure and previous studies

A total loss of feedwater (TLOFW) accident is used to represent an accident involving the failure of cooling by the secondary cooling system. In a very short period of time, the turbine and the reactor trip either directly due to turbo-pump trip or indirectly due to a low narrow-range level in steam generator. Once the reactor has been tripped, the operators start following the EOP-00 "Standard Post Trip Action" in the case of OPR1000. The operators perform a preliminary diagnosis of the events which has resulted in a reactor trip using the EOP-01 "Diagnostic Actions". After the diagnosis of event, the operators follow the EOP-05 "Loss of All Feedwater" of which main steps are: Stoppage of all reactor coolant pumps (RCPs), securing the water inventory of steam generators, and checking the criteria for F&B operation. When at least one pressurizer safety valve (PSV) has opened after steam generator dryout, the procedure instructs that operators implement "RCS and Core Heat Removal success path" [3][4][5].

Once the wide-range level of two steam generators becomes less than 2%, all SDS valves are opened and HPSI pumps are activated. After this point, operators need to monitor the main parameters of the plant such as primary pressure and core outlet temperature. After a period of time, the plant will be cooled down and the final steps of the procedure aim to properly stop the HPSI pumps and to close SDS valves once the plant has been recovered. Finally, the operators initiate shut down cooling system operation [4][5].

Previous studies have focused on accidents involving a TLOFW to demonstrate the use of an F&B operation [6][7][8][9]. Reventós et al. characterized the procedure for an F&B operation in a TLOFW accident and provided plant behavior analysis under the partial availability of systems at the Ascó NPP [8]. The maximum allowable time until the procedure must be initiated and a number of considerations for heat sink recovery in a TLOFW accident were also addressed. Sherry et al. identified the most important parameters likely to influence whether core damage would occur during a TLOFW accident [10].

Although considerable research has been devoted to the F&B operation, operators continue to have difficulties in deciding on the initiation of an F&B operation. They may hesitate if a clear cue is not provided because its initiation implies a release of radioactive coolant into the containment structure. The OPR1000 has an optimized recovery procedure (ORP) for diagnosing a TLOFW accident and a functional recovery procedure (FRP) for an F&B operation. Although these procedures are designed to guide the operator's mitigation actions during a TLOFW accident, there is a high probability of the operator incorrectly initiating an F&B operation because the time available for a diagnosis of the F&B operation is very limited [3]. In the case of a combined accident that includes a failure of the secondary cooling system, it is difficult for operators to recognize the necessity of an F&B operation because numerous process parameters and alarms must be checked before a decision can be made, and operators may spend a considerable amount of time arriving at the entry for a proper FRP that contains the procedure for an F&B operation.

3. Considerations for operation strategy to initiating of F&B operation

When operators decide whether the F&B operation initiate or not, the operators should check the several process parameters and components status. As mentioned previous paper, the plant conditions that require an F&B operation are categorized as transients caused by a loss of feedwater (Type 1 accidents) and LOCA (loss of coolant accident) with transients caused by a loss of feedwater (Type 2 accidents) [2].

From operator perspective, Type 1 accident can be considered as failure of secondary side with several malfunctions of safety systems, but, Type 2 accident is different from Type 1 accident. It is not necessary to initiate an F&B operation in the case of a medium or large break because these cases correspond to low RCS pressure sequences when the secondary side is failed. If the break size is too small to sufficiently decrease the RCS pressure, the F&B operation is necessary. Moreover, even if the size is not small, the F&B operation may need to cool down the core when the time gap between TLOFW and break increases much. When a LOCA and a failure of the secondary cooling system occur simultaneously, numerous alarms become active and the operator may become more confused [2].

As mentioned in previous paper, the operator should check the States. Steam generator level, core level, RCS pressure, and RCS temperature are most important factors to identify the necessity of F&B operation. The amount of safety injection is a key parameter in determining the necessity of an F&B operation in the case of Type 2 accidents [2]. Therefore, the detective parameters, which can make the criteria of States to check, should be checked by operators after operators recognize the failure of secondary side. Especially, in the case of Type 2 accidents, the availability of high pressure safety injection (HPSI) pumps can be checked before the F&B operation is initiated.

The peak cladding temperature (PCT) is the primary parameter to determine the transition point. Yun. J, et al.'s paper mentions that the transition to the SAMG is required at the temperature over which the breakaway oxidation phenomena start to occur at the fuel. The PCT of oxidation breakaway was assumed to be 982℃ based on their paper's references [11]. Karanki et al.'s paper insists that core damage is assumed for sequences with a PCT above 1477K (2200˚F). Sequences with the PCT approaching or briefly exceeding 1477 K are also conservatively assumed to lead to core damage since some fraction of these may exceed 1477 K after accounting for uncertainties [12]. Core exit temperature (CET) is the alternative parameter to check the PCT indirectly. Although the different types of NPPs have different cladding materials and system designs, the identical CET, i.e., 650℃, is applied as the entry condition to the severe accident management guideline (SAMG) of all the NPPs (except CANDU plants [11]. The identical CET, i.e., 650℃ is limitation of initiating the F&B operation by FRP in OPR1000 [4].

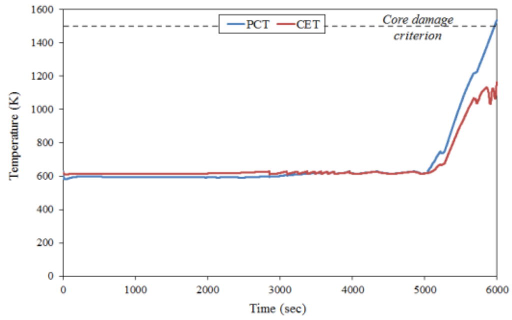

Fig. 1. PCT and CET when the case of TLOFW accident occurs.

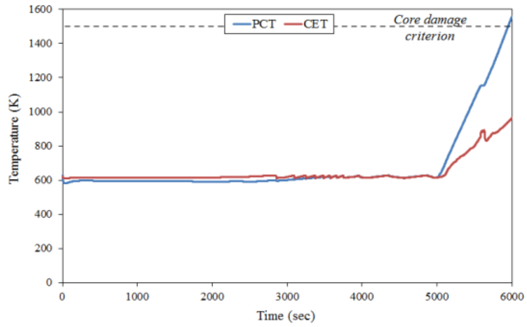

Fig. 2. PCT and CET when 1.0 in. break occurs 5000 s after TLOFW accident occurs.

The CET for limitation of F&B operation in FRP should be re-evaluated for combined accident. In the case of Type 2 accidents, the CET can be changed different from CET of TLOFW accident. As shown in the Fig. 1 and 2, the PCT trends are similar, but, the CET trends are different. Figure 2 case is the 1.0 in. break and break occurs 5000 s after TLOFW accident occurs. Fig. 2 condition is two HPSI pumps available. The CET of Fig. 2 is less than the CET of Fig. 1 at the same PCT. The CET trend is affected by break flow, pressurizer safety valves (PSV) flow, and safety injection (SI) flow since the core level and pressure are related to change of the CET. During the opening of PSVs, the pressure does not change a lot, but, the core inventory is affected by PSVs flow. In the case of Type 2 accidents, the break flow and SI flow are dominant factors of the core inventory. If the core inventory is insufficient to transfer heat from the cladding to water, the temperature increases less. With several sensitivity studies, we can estimate the relationship between CET and PCT under various plant conditions. If the correlation between CET and PCT under various plant conditions can be identified, the limitation of initiating the F&B operation can be established.

4. Conclusions

Previous studies have usually focused on accidents involving a TLOFW accident. The plant conditions to make the operators confused seriously are usually the combined accident because the ORP only focuses on a single accident and FRP is less familiar with operators. The F&B operation is last resort to prevent core damage when the secondary side is failed. The plant is not always necessary the F&B operation when the secondary side is failed. If the break size is large enough to inject sufficient coolant by safety injection system, the F&B operation is not necessary. To investigate the necessity of F&B operation from the viewpoint of operators, the advanced operation strategy is necessary.

Steam generator level, core level, RCS pressure, and RCS temperature are most important factors to identify the necessity of F&B operation and degree of plant urgency. The amount of safety injection is a key parameter in determining the necessity of an F&B operation and degree of plant urgency in the case of Type 2 accidents. The observable parameters should be checked by operators after operators recognize the failure of secondary side. Especially, in the case of Type 2 accidents, the availability of HPSI pumps can be checked before the F&B operation is initiated. Based on the SI flow, the operator can expect the possibility of F&B operation, and the initiating time of F&B operation to prevent core damage can be estimated if the availability of safety depressurization system (SDS) valves is monitored. Therefore, the operation strategy should be reflected the States with important factors.

The relationship between CET and PCT under various plant conditions is important to decide the limitation of initiating the F&B operation to prevent core damage. The CET trend is affected by break flow, PSVs flow, and SI flow because the core level and pressure are related to change of the CET. If the correlation between CET and PCT under various plant conditions can be identified with several sensitivity studies, the limitation of initiating the F&B operation can be established.

ACKNOWLEDGEMENT

This work was supported by the KUSTAR-KAIST Institute, Korea, under the R&D program supervised by the KAIST.

REFERENCES

[1] Kim, B. G et al., Dynamic Sequence Analysis for F&B Operation in OPR1000, Annals of Nuclear Energy, Vol. 71, 361–375, 2014.
[2] Kim, B. G et al., A Study on the Operator Decision Support for Feed-and-Bleed Operation, Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, 2014.
[3] Jung, W. et al., Analysis of an Operators' Performance Time and Its Application to a Human Reliability Analysis in Nuclear Power Plants, IEEE Transactions on Nuclear Science, Vol. 54, No. 5, 1801-1811, 2007.
[4] KHNP, 2001, Functional Recovery Guideline of OPR1000, Korea Hydraulic and Nuclear Power Co.
[5] Reventós, F. et al., Analysis of the Feed & Bleed procedure for the Ascó NPP First approach study for operation support, Nuclear Engineering and Design 237, 2006-2013, 2007.
[6] Kwon, Y.M. et al., Comparative simulation of feed and bleed operation during the total loss of feedwater event by RELAP5:MOD3 and CEFLASH-4AS:REM computer codes. Nucl. Technol. 112, 181–193, 1995..
[7] Kwon, Y. M., Song, J. H., Feasibility of Long Term Feed and Bleed Operation For Total Loss of Feedwater Event, Journal of the Korean Nuclear Society, Volume 28, Number 3, 257–264, 1996.
[8] Park, R. J. et al., Detailed evaluation of coolant injection into the reactor vessel with RCS depressurization for high pressure sequences, Nuclear Engineering and Design 239, 2484–2490, 2009.
[9] Pochard, R. et al., Analysis of a feed and bleed procedure sensitivity study, performed with the SIPACT simulator, on a French 900 MWe NPP, Nuclear Engineering and Design 215, 1-14, 2002.
[10] Sherry, R. et al., 2013, Pilot application of risk informed safety margin characterization to a total loss of feedwater event, Reliability Engineering and System Safety 117, 65–72.
[11] Yun. J, et al., Verification of SAMG entry condition for APR1400, Transactions of the Korean Nuclear Society Autumn Meeting, Gyeongju, Korea, 2013.
[12] Karanki et al., The Impact of Dynamics on the MLOCA Accident Model – An Application of Dynamic Event Trees, PSAM11/ESREL2012, Helsinki, Finland, 2012.